14. The continual reciprocal action, between attracting centres, $\left(g \propto \frac{\mu}{d^2}\right)$ of disturbances proportional to mass.

15. The limiting influence of parabolic velocities, upon tendencies to dissociation and to aggregation.

16. The ratio of stress-opposing force, at Laplace's limit, to parabolic $\left(\frac{\pi}{\sqrt{2}}\right)$ and to orbital (π) velocity.

17. The influence of centres of linear and of spherical oscillation.

18. The conjoint influence of centres of nucleation, of density, of nebulosity, of rotary inertia, and of reciprocity.

19. The equations of relation between oscillatory and orbital motion.

20. The interesting and suggestive FACT, important in chemistry and general physics as well as in astronomy, that the central stress-opposing value in the solar system $\left(\frac{gt}{2}\right)$ is the velocity of light.

The Relations of the Crystalline Rocks of Eastern Pennsylvania to the Silurian Limestones and the Hudson River Age of the Hydromice Schists. By Charles E. Hall. With a Plate.

(*Read before the American Philosophical Society, January* 2, 1880.)

Recently Prof. Frazer called the attention of the Academy of Natural Sciences to the fact of the occurrence of the fossil *Buthotrephis flexuosa* in the Peach Bottom roofing slates of York county, Pennsylvania. As Prof. Lesquereux admits that this fossil does not extend below the Trenton limestone, it is in all probability within the Hudson river group. Dr. Emmons assigned this fossil to the Taconic System. Since Dr. Emmons' time, I think the fossiliferous bed of the Taconic system have been pretty well proven to be of the Cambrian series, which would place this Taconic fossil of Emmons somewhere about the Hudson river group.

I embrace this opportunity to state some facts from which I have drawn conclusions concerning the relative positions of the rocks forming the crystalline series of Eastern Pennsylvania.

I shall endeavor to make my statements concise, and I think my reasoning will be understood.

We have the following series of rocks:

First. A series of granitoid, syenitic, quartzose, and micaceous schistose rocks, to be seen on the Delaware river above the city bridge at Trenton, and extending in a south-easterly belt across Bucks and Montgomery counties, as far west as Chestnut Hill, Philadelphia.

Second. A series of syenitic, hornblendic and quartzose rocks extending from the neighborhood of Chestnut Hill westward across the Schuylkill river, and covering a greater part of the northern portion of Delaware county. Fine exposures of this rock are to be seen on the Schuylkill river below Spring Mill, Montgomery county. This series may be the upper members of the first, or that extending from the Delaware river to Chestnut Hill.

Third. Potsdam sandstone, conglomerate, quartzite, and occasional schistose beds. In this group is included the Edge Hill rock which extends in an unbroken ridge from the Delaware river at Trenton to Huntingdon Valley in Montgomery county, and another ridge of the same rock from a point south of Willow Grove to Spring Mill, Montgomery county, near the Schuylkill river. The Edge Hill sandstone is identical with the quartzites flanking the north side of the limestone valley of Montgomery and Chester counties, and merges into them about Willow Grove. This, the Potsdam sandstone, rests unconformably upon the preceding two groups. The unconformity is seen at points east of Willow Grove, where the lower conglomerates contain fragments of the syenitic rocks.

Fourth. Dolomites, schistose or slaty micaceous beds, limestone, marble, hydromica schists and bastard marble. This group of limestones and schists rest upon the above group, and are the equivalent of the Cambrian limestones of the Great Valley. Trenton fossils have been found in the upper part of this group at Buckingham, Bucks county, by Mr. Ash. This Bucks county belt of limestone is cut off from the limestones of Chester Valley by the New Red Sandstone. There is no apparent unconformity throughout the limestone group. The lower beds are Dolomites; there are occasional alternations of shale throughout the mass. The marbles are all confined to the upper horizon and are followed by alternations of shale and shaly limestone.

Fifth. Hydromica schists, quartzose schists, chloritic schists, and occasional beds of quartzites and sandy beds and serpentines. It is difficult to draw a line between this group and the limestones, which pass into it by alternations exactly as the Trenton limestone passes into the shales of the Hudson river group in Central Pennsylvania. These are the Hudson river shales and flank the Chester Valley on the south from some point not far east of the Schuylkill river throughout the entire length of the valley. They extend south to the syenitic rocks of the second group, and west of the Schuylkill to the neighborhood of the Brandywine creek in Chester county, and gradually widening out to the south-west.

Sixth. Micaceous, garnetiferous schists, limestone in beds which rapidly thin out to the eastward, mica schists, and sandstones. The area of this group I have not determined, but it is principally confined to the southern central portion of Chester county, resting upon the Hydromica schists of the group above-mentioned. The eastern boundary is about the line of the Brandywine creek, although a tongue extends east of the creek to the neighborhood of Dillworthtown. This group rests unconformably upon the western extension of the *second* group.

Seventh. The mica schists of Philadelphia, mica schists, hornblendic, garnetiferous, talcose schists with soapstone and serpentine. These rocks lie to the south of the first and second groups of rocks, and are cut off on the west and south by the rocks of the second group from any connection with the rocks of Chester county. They rest unconformably upon the

first, second, third and fourth groups and are somewhat different in character from the fifth group, though they resemble portions of the sixth group.

There are besides these groups probably two serpentine horizons, which are undoubtedly unconformable deposits above the second group. I think the northern belt of serpentine may be considered as altered Hudson river rock; while the southern belts are doubtful.

The *first* and *second* groups are the oldest rocks, overlaid by the Potsdam sandstone unconformably. The Potsdam is flanked on the south by the *first* from Willow Grove to Chestnut Hill, where this group seems to be succeeded by the *second*. It may be only the upper part of the first, however, the sandstone rests on both. The *first* group is flanked on the south by the Edge Hill rock or Potsdam S. S. from the Delaware river to the Pennepack creek in Montgomery county. To the north the upturned edges of these rocks are overlaid by the New Red Sandstone. West of the Pennepack creek the structure is plainly a synclinal, the axis of which would be just south of Willow Grove; and an anticlinal, the axis being about on a line from Abington to Attleboro.

The syenitic rocks flank the Potsdam on the north of the synclinal north of Willow Grove, encircle the end of the synclinal and are exposed along the anticlinal to a point near Chestnut Hill. The Potsdam sandstone is not found between Huntingdon Valley on the Pennepack and Waverly Heights, south-west of Edge Hill P. O., along the south side of the anticlinal.

The overlying limestone occurs just south of Huntingdon Valley, overlying the sandstone, and extends westward beyond the Pennepack creek some distance, lying *immediately above* the gneisses of the first group.

The unconformity is evident between the gneisses of the first group and the limestones, and inasmuch as the limestone occurs almost on the line of strike of the sandstone which again appears at Waverly Heights, it would seem to be sufficient proof of its unconformity to the sandstone.

Resting on the Potsdam sandstone from the neighborhood of the Delaware river to a point near Huntingdon Valley, and on the limestones between Huntingdon Valley and Waverly Heights, and also on the Gneisses of the first group, we have the micaceous, garnetiferous schists of the Philadelphia group. These are unconformable, resting upon and against these lower rocks.

The sandstone along the south margin of the synclinal, which I spoke of as extending from Willow Grove to the Schuylkill is, most of it, very different in character to that along the north side. The difference in character on the north and south sides of the valley may be due to the infiltration of ferruginous matter derived from the New Red sandstones which flank the group and overlap it on the north.

The dips are high, the rocks are sandy, light colored and very free from iron as a rule; the ridge is known as Edge Hill. Towards the Schuylkill it dies down rapidly, and disappears below the limestones at Spring Mill, not only swallowed up by a fault, but unconformably overlapped as well.

On the north side of this synclinal valley, we find the quartzites and

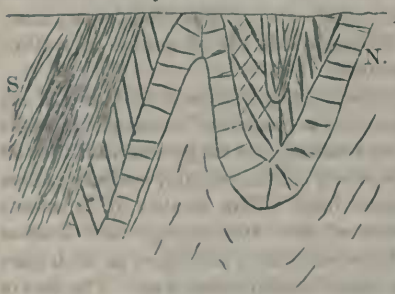
sandstones forming prominent ridges, having a much less dip and covering greater areas. There are several cynclinals and anticlinals, the axes of which form an obtuse angle to the line of strike of Edge Hill. These folds die down very rapidly to the eastward, but are marked by slight irregularities in the line of strike of Edge Hill.

I have been long inclined to consider the elevations of sandstone along the north flank of the limestone valley, as having been caused by folds and faults, but I do not see any proofs of faulting. But there is evidence of unconformity between the two groups, as at Spring Mill, where the limestone overrides the upturned Potsdam; at a point west of the second crossing of Sandy Run by the North Penn. R. R., just south of Fort Washington, the limestone occurs in a bay in the sandstone, having a slighter dip. Just south of Mogeetown, east of the Schuylkill river, near Norristown, the limestones rest unconformably upon the Potsdam, to all appearances.

The anticlinal ridges of Potsdam extending diagonally into the valley, are flanked on both sides by limestone, and, in some cases, disappear below the limestone which encircles it; but in the most eastern fold I doubt whether the limestone is connected.

The marble is confined to the south side of the valley. The dip of the limestone being to the south, it would place them at or near the top. Marble quarries are found in Chester county, close along the southern margin of the limestone valley, and in close proximity to the slates. In Montgomery county the same rule holds good, and very shortly after the disappearance of the slates to the east of the Schuylkill, we find the marble is missing as well.

The rocks rise rapidly to the eastward. The slates of the South Valley Hill are in regular succession upon the limestone. This may be seen where the South Valley Hill ends at Gulf Mills. The structure is clearly proven by the succession of rocks, which is marble, bastard marble, shale, on the north side of the synclinal and a double repetition on the anticlinal at Gulf Mills. The cove made by the erosion of the anticlinal is just west of Gulf Mills, west of Conshohocken. The transition shaly limestones are repeated several times by minor contortions, and extend over a wide area from Gulf Mills to the Schuylkill river.



The alternations from the limestone into the slates is everywhere visible along the southern margin of the Chester valley.

The slates are traversed by a trap dyke, which crosses the Schuylkill at Conshohocken. I do not think it marks the line of any disturbance of importance. The synclinal and anticlinal of the slates do not cross the Schuylkill river. The slates flanking the marbles east of the Schuylkill lie in a monoclinal, pitching to the south against the Potsdam, which was

upturned along the line from Spring Mill to Edge Hill P. O., probably prior to their deposition. This is evident from the fact that the limestones lap over the rocks of the second group at West Conshohocken.

It may be that the great unconformity of the measures west of the Schuylkill river cannot be explained without a fault along the line of junction.

The southern margin of the slates of the South Valley Hill is somewhat irregular, they come in contact with the rocks of the *second* group as far west as the east branch of the Brandywine creek, or that neighborhood, where they are succeeded and overlaid by micaceous garnetiferous rocks with limestone of the *sixth group.*

The southern boundary of the South Valley Hill slates or Lower Hudson river slates, is about on a line from West Conshohocken to a point about four miles north-west of West Chester, and gradually diverges from the line of the Chester valley as we proceed westward. This divergence is caused partially by the flattening of the measures, and partially by their increased thickness.

The sixth group which flanks the South Valley Hill rocks on the south and overlies them, increase rapidly in thickness to the west of the Brandywine creek. This group lies upon the rocks of the *second* group and encircles the western end of that area. The East Branch of the Brandywine creek cuts along close to the line of junction, between these groups. The schists in places are found on both sides of the creek, while at other points the syenitic rocks of the *second* group extend west of the line. The limestones of this group are well exposed in the neighborhood of Doe Run. The most easterly exposures are at Caleb Cope's and Copesville on the Brandywine; also at Brinton's Bridge on the Brandywine, and two localities east of Brandywine creek, one in Birmingham and the other in Thornbury township.

The locality at Caleb Cope's place, north-west of West Chester, is a similar deposit to the one at Brinton's Bridge, a thin bed of impure crystalline limestone between beds of schistose rock.

The first locality is on a line with the locality at Cope's Mill, and as can be seen by the map, is also on a line with a number of limestone quarries west of it. I have satisfied myself by walking over the ground that they all belong to one horizon, and if not absolutely continuous they are only broken by the thinning out of the limestone itself. The locality at Brinton's Bridge is on a line with the quarries of East Marlborough and London Grove townships, and although it is a small bed, it is flanked on both sides by the same rocks which flank the heavier beds further west. The fact of it being a thin bed bears me out in the assertion that all these beds thin rapidly towards the east.

I am not prepared to say whether or not there is more than one horizon of limestone in this portion of Chester county. I am forced to the conclusion as to its superposition to the South Valley Hill slates, as the succession is clearly seen along the East Branch of the Brandywine Creek.

The rocks of this group seem to vary considerably, and it is not improbable that they may have to be subdivided, as I have included all the

schistose rocks with limestone from the South Valley Hill slates along the East Branch of the Brandywine to Chadd's Ford or the Maryland line, and west at least as far as Avondale, Chester county. From their position above the slates of the South Valley Hill, which are Hudson river, they belong to a limestone group above the Hudson river group. Inasmuch as no fossils have been found as yet, it is difficult to assign them to any particular age, but I am inclined to think that they may be Silurian and possibly Helderberg.

There may be an unconformity between these schists and sandstones and the slates below, but as yet I have not been able to determine the area of the upper group accurately, and before this is done it is impossible to state decidedly what the relation is.

In Eastern New York, south-west of Albany, we find the Hudson river shales and sandstones overlaid by the Niagara in thin beds of concretionary limestone, often not recognizable, followed by the Helderberg limestone, the Oneida conglomerate, Medina sandstone, the Clinton group, and Onondaga shales, all having died out east and north before reaching the Helderberg escarpment. May we not have similar structure here?

The limestones of the Chester Valley extend in an almost straight line from the Schuylkill river to the neighborhood of Quarryville, in Lancaster county, where the straight valley ends and connects with the great limestone valley of Lancaster county at Camargo P. O.

At Camargo P. O., according to Prof. Frazer's map, a tongue of slates connects across the limestone and is colored the same as an area of rock north of the limestone valley, extending to the county line south and east of the Gap P. O.

The limestone valley from the Schuylkill to Quarryville or thereabouts is a monoclinal, the beds all pitching to the southward, followed by Chloritic schists, Hydromica schists and Mica schists, which overlie the limestones. This is clearly demonstrated at the eastern end of the South Valley Hill, which is formed by these slates. The marbles, which are always confined to the southern edge of the valley, mark the horizon of the Trenton limestone with its alternations of slate and slaty limestone, passing by alternations into shale and slate of the South Valley Hill or Hudson river group. Just north of Gulf Mill a synclinal of the slates dies out, and at Gulf Mill we have a double repetition of the alternations of impure limestone and slate found flanking the synclinal on the north, which proves Gulf Mill to be on an anticlinal axis. (See wood cut.)

The dips, as a rule, are pretty high towards the Schuylkill river, varying from 50° to 85°. But as we proceed westward they become somewhat less, which may in part account for the widening of the slate area before spoken of, but there is a marked thickening in the beds to the southwestward, which also must be taken into consideration.

Owing to the short time I have for the preparation of this paper, I will proceed to carry these determinations of horizons south-westward.

At Camargo P. O., we would have an anticlinal of slates overlying the limestones, which anticlinal would be on a line of the axis of the Tocquan creek anticlinal recognized by Prof. Frazer on the Susquehanna.

The lower portion of Pequea creek flows along an anticlinal in which the limestone is exposed along the creek to the neighborhood of Marticville P. O. A tongue of slates extends eastward between the Pequea and Conestoga creeks as far as Willow Street P. O., which is on a line of a synclinal axis shown to end at Compassville, and along which the Pequea creek flows from Compassville to Wheatland Mills P. O. An anticlinal having its axis about on a line between Petersville P. O. and the mouth of Conestoga creek. A synclinal of Chloritic slates ending somewhere near Indian town. An anticlinal exposing the limestone, extending from Prospect Furnace P. O., in York county, to Lancaster.

A synclinal of slates extending from a point south-east of Montville P. O. to Washington Manor P. O., and crossing the river, is evident from the distribution of slates in York county, beyond the line of the Peach Bottom R. R. Lastly, we have a monoclinal flanking the Chickis Potsdam, extending from Hempfield, which is at the extreme eastern end of the Potsdam anticlinal through Columbia in Lancaster county, and Wrightsville, York, Springforge to Hanover in York county. North of York the limestone is not continuous across to the northern arm of the anticlinal, which is principally covered by the Trias, but has a considerable exposure in Lancaster county. The slates, therefore, south-east of the limestones of Chester county, are of Hudson river age.

The slates of York and Lancaster counties, which includes the roofing slates of Peach Bottom, are a continuation of those of Chester county, which flank the limestone on the south, and are referable to the same group.

The serpentines of Radnor township, Delaware county, and those of Easttown, Willistown, East and West Goshen, are undoubtedly altered beds of the South Valley Hill slates, or Hudson river slates. They lie unconformably upon the syenitic rocks of the second group.

The probability is that all the serpentines of Chester county will be found to belong to the Hudson river group, and are possibly pretty nearly on the same horizon as the limestones of West Bradford, Merlin, east and west Marlborough, London Grove, Kennet, and other townships of southern Chester county, although I have spoken of this limestone group as being possibly of Helderberg age. The serpentines of southern Lancaster county are undoubtedly altered beds of the Hudson river group, and from their relative position to the roofing slates of Peach Bottom, would be in their proper place.

Dr. T. Sterry Hunt insists that the serpentines of the Schuylkill are below the Philadelphia schists. If they are, the structure would be even more simple than otherwise. Placing them below the Philadelphia schists they would be on a horizon with the serpentine beds of Chester county, and these Philadelphia rocks equivalent to those which they resemble in southern Chester county : but if the serpentines of Montgomery and Delaware counties are above the Philadelphia series, they necessarily belong to a later age than those of the Hudson river group.

At present I am inclined to place these serpentines above the Philadel-

phia rocks, and, by so doing, assign the Philadelphia series to a higher group than the Hudson river.

The relation of the Philadelphia schists to the schists of the *sixth* group is not fully determined, but they bear a great resemblance to them, and in many respects are identical. The syenitic rocks of Delaware county which belong to the *second* group, cut off the connection between them.

To all appearances the serpentine belts, which are visible on the Schuylkill river at Lafayette station, Montgomery county, and at a point just north of them, are above the mica schists of Philadelphia. The southern belt extends in an almost unbroken line from Chestnut Hill, Philadelphia, to Bryn Mawr, in Montgomery county. A less prominent belt extends from the Schuylkill river to the neighborhood of Rosemont station, on the Pennsylvania R. R., in a parallel line to the first belt.

The serpentines of Delaware county are on a general line of strike with these belts, and without doubt represent the same horizons.

There is no evidence in this section of the Oneida conglomerate or Medina sandstone, as far as I can observe, but there are sandstones in the south-eastern portion of Chester county I have classified with the sixth group, which may prove to belong to a sandstone formation succeeding the Hudson river slates.

LIMESTONE.

MICA SCHISTS.

III. { SERPENTINES. GARNETIFEROUS SCHISTS. HYDROMICA SLATES. CHLORITIC SLATES. ALTERNATIONS OF SLATE AND LIMESTONE.

II. { MARBLE. SLATE. DOLOMITES.

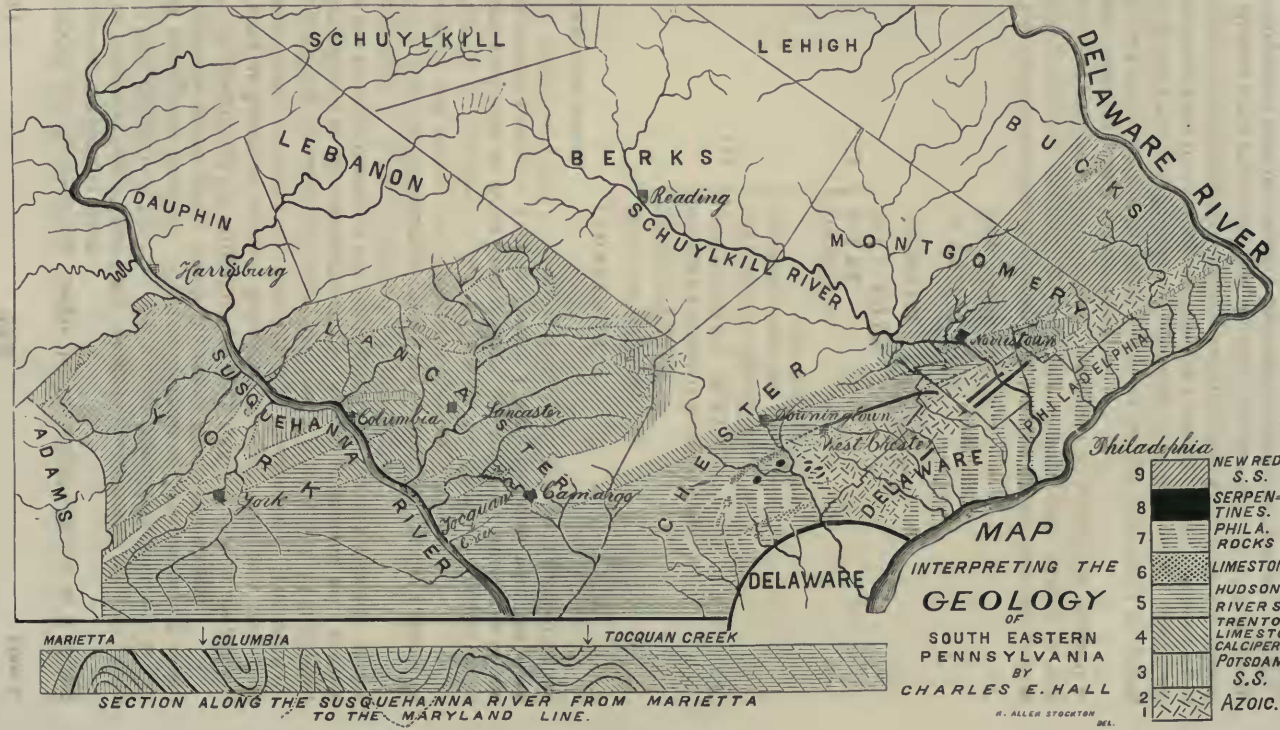
I. POTSDAM { SANDSTONE. QUARTZITE.

SYENITIC AND GRANITIC ROCKS.

There is no doubt that magnesian beds may be altered into serpentines wherever they may be, and the mere fact of serpentine existing at any place is not proof of a given horizon, but it is in all probability confined to definite horizons within limited areas.

The whole question of structure would be easily solved could we prove what is everywhere indicated, viz, a gradual subsidence of the formations north-west of the line of junction between the South Valley Hill slates and the syenitic rock of the *second* group, which change in level, at the close of the Hudson river group, allowed the upper magnesian beds of that group to be deposited over the edges of and encircle the *second* group.

The evident nonconformity between the Philadelphia schists and the


SCHUYLKILL
LEHIGH
DELAWARE RIVER
LEBANON
BERKS
BUCKS
DAUPHIN
Reading
Harrisburg
SCHUYLKILL RIVER
MONTGOMERY
Norristown
PHILADELPHIA
LANCASTER
YORK
SUSQUEHANNA RIVER
Columbia
Lancaster
Quarryville
West Chester
DELAWARE
Philadelphia
ADAMS
York
Tocquan Creek
Carnahgo
CHESTER
DELAWARE
MARIETTA
COLUMBIA
TOCQUAN CREEK
SECTION ALONG THE SUSQUEHANNA RIVER FROM MARIETTA TO THE MARYLAND LINE.
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OF
SOUTH EASTERN
PENNSYLVANIA
BY
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8 SERPENTINES.
7 PHILA. ROCKS
6 LIMESTONE
5 HUDSON RIVER SL.
4 TRENTON LIMESTONE CALCIPEROUS
3 POTSDAM S.S.
2
1 AZOIC.
H. ALLEN STOCKTON DEL.